UNIVERSITI PUTRA MALAYSIA

# *HARVEST AGE AND PLANTING DENSITY EFFECTS ON YIELD AND QUALITY OF TWO KENAF (HIBISCUS CANNABINUS l.) VARIETIES FOR FIBRE AND ANIMAL FEED*

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**By**

**MASNIRA BINTI MOHAMMAD YUSOFF**

**Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfillment of the Requirements for the Degree of Master of Science**

**April 2015**

**Specially dedicated to my husband, family and friends for their continued support and everlasting love**

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirements for the Degree of Master of Science

**HARVEST AGE AND PLANTING DENSITY EFFECTS ON YIELD AND QUALITY OF TWO KENAF (H*ibiscus cannabinus* L.) VARIETIES FOR FIBRE AND ANIMAL FEED**

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**Chairman:** **Associate Prof. Mohd Ridzwan bin Abd Halim, PhD**
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Kenaf (*Hibiscus cannabinus* L.*)* has been identified as a viable alternative crop to replace tobacco in Malaysian agriculture in the 21st century. Kenaf can be utilized for multiple purposes, whether for industrial applications or for livestock feed. Much information on components of yield such as plant height and density, stalk and leaf yield and total biomass have been obtained for the variety V 36. However, information on the new variety, MHC 123 is lacking, especially the understanding on how the yield components are affected by plant density and age. As plant density usually has an interaction with variety and harvest age the study looked at these factors in factorial combinations. From this information the optimum age and planting density for production of feed and fibre can be determined. The study was comprised of two experiments, one looking at harvest age and the other one on planting density effect.

The first experiment had four harvest age treatments (8, 12, 16 and 20 weeks after planting) and two varieties (MHC 123 and V 36) as the treatments. The results indicated that the most suitable harvesting age for forage for kenaf variety V 36 was at 8 weeks after planting (WAP) while for MHC 123 it was at 12 WAP. This is based on the low decline in crude protein content from 8 to 12 WAP in MHC 123 (18.9 to 17. 2 %) compared to the rapid decline for V 36 (21.7 to 11.3 %). In addition, acid detergent fibre content in MHC 123 increased slowly (31.7 to 36.9 %) but in V 36 it increased drastically (39.5 to 55.6 %) from 8 to 12 WAP. Dry matter yield also was higher at 12 WAP (11.2 t $ha^{-1}$) compared with 8 WAP (8.5 t $ha^{-1}$) for MHC 123.

The harvesting age for fibre was based on biomass yield and fibre quality (tensile strength, water absorption, bast and core yield). The suitable harvesting age for MHC 123 and V 36 were at same age, 16 WAP. However, MHC 123 had greater biomass yield with 11.7 t $ha^{-1}$ compared to V 36 which was 8.7 t $ha^{-1}$. The tensile strength of the fibre from MHC 123 (101.7 MPa) was higher than that of V 36 (59.8 MPa). Fibre from MHC 123 absorbed less water (116%) compared to V 36 (124.3%). The bast yield was also higher in MHC 123 (3.4 t $ha^{-1}$) compared to V 36 (3.3 t $ha^{-1}$).

In the second experiment, there were 3 treatment combinations: planting density, harvest age and variety in split-split plot design with 4 replications. Harvest age was set as the main plot, planting density as a sub plot and variety as a sub-sub plot. The suitable plant density for MHC 123 and V 36 for forage was at 666,700 plants $ha^{-1}$. This was based on MHC 123 and V 36 having higher CP content and lower ADF content at planting density of 666,700 plants $ha^{-1}$.

Planting density of 444,400 plants $ha^{-1}$ was the best for fibre production for MHC 123 and V 36. This was based from the finding that MHC 123 and V 36 were higher in dry matter yield, bast yield, core yield at density of 444,400 plants $ha^{-1}$. The dry matter yield was significantly ($p<0.05$) higher at the lowest density, 444,400 plants $ha^{-1}$ with 12.7 t $ha^{-1}$, followed by decreasing dry matter yield of 11.5, 11.2 and 10.3 t $ha^{-1}$ for plant density at 500,000, 571,500, and 666 700 plants $ha^{-1}$ respectively. MHC 123 has a potential to replace V 36. The superiority of MHC 123 over V 36 includes the higher leaf yield, stem yield, number of leaf $plot^{-1}$, leaf to stem ratio, leaf area index (LAI), number of day to flowering and bast yield. The result of this study indicated that optimum harvest age and planting density vary with the variety of kenaf.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Master Sains

**KESAN KEPADATAN TANAMAN DAN UMUR PENUAIAN TERHADAP HASIL DAN KUALITI DUA VARIETI KENAF (H*ibiscus cannabinus* L.) UNTUK PENGELUARAN SERAT DAN MAKANAN TERNAKAN**

Oleh

**MASNIRA MOHAMMAD YUSOFF**

**Januari 2015**

**Pengerusi:** **Profesor Madya. Mohd Ridzwan bin Abd Halim, PhD**
**Fakulti:** **Pertanian**

Kenaf (*Hibiscus cannabinus* L.) daripada family Malvacea, telah dikenalpasti sebagai tanaman alternatif menggantikan tembakau untuk pertanian Malaysia pada abad ke-21. Kenaf boleh digunakan untuk pelbagai kegunaan sama ada untuk kegunaan perindustrian atau makanan ternakan. Kebanyakan maklumat berkenaan komponen hasil seperti ketinggian pokok dan kepadatan, hasil batang dan daun dan jumlah hasil biomass yang diperolehi adalah berdasarkan V 36. Walaubagaimanapun, maklumat tentang varieti baru, MHC 123 masih lagi kurang, terutamanya mengenai bagaimana komponen hasil dipengaruhi oleh kepadatan dan umur pokok. Kepadatan tanaman kebiasaanya mempunyai perkaitan dengan varieti dan umur tuaian, kajian ini dijalankan dengan faktor tersebut dengan kombinasi factorial. Melalui maklumat ini, umur optimum dan kepadatan tanaman optimum untuk pengeluaran makanan ternakan dan serat boleh ditentukan. Kajian melibatkan dua eksperimen, pertama mengenai umur penuaian dan satu lagi kesan kepadatan tanaman.

Eksperimen 1 melibatkan empat rawatan umur penuaian (8, 12, 16 dan 20 minggu selepas tanam) dan 2 varieti (MHC 123 dan V 36). Keputusan menunjukkan umur penuaian yang paling sesuai untuk makanan ternakan untuk kenaf varieti V 36 adalah pada 8 minggu selepas tanam (MST) manakala untuk MHC 123 adalah pada 12 MST. Ini adalah berdasarkan kepada penurunan yang perlahan kandungan protein kasar daripada 8 kepada 12 MST dalam MHC 123 (18.9 kepada 17. 2%) berbanding penurunan mendadak dalam V 36 (21.7 kepada 11.3%). Tambahan pula, kandungan serat detergen acid (ADF) di dalam MHC 123 meningkat dengan perlahan (31.7 kepada 36.9%) tetapi di dalam V 36 ia meningkat secara drastik (39.5 kepada 55.6%) daripada 8 kepada 12 MST. Hasil berat kering juga lebih tinggi pada 12 MST (11.2 t $ha^{-1}$) berbanding pada 8 MST (8.5 t $ha^{-1}$) untuk MHC123.

Umur penuaian untuk serat adalah berdasarkan hasil biomassa dan kualiti serat (kekuatan tegangan, serapan air, hasil serat luar dan dalam). Umur penuaian yang sesuai untuk MHC 123 dan V 36 adalah pada umur yang sama, 16 MST.

Walaubagaimanapun, MHC 123 mempunyai hasil biomassa yang lebih tinggi iaitu 11.7 $tha^{-1}$ berbanding V 36 dengan 8.7 t $ha^{-1}$. Kekuatan tegangan serat MHC 123 (101 Mpa) adalah lebih tinggi daripada V 36 (59.8 MPa). Serat daripada MHC 123 menyerap air lebih rendah (116%) berbanding dengan V 36 (124.3%). Hasil serat luar MHC 123 (3.4 $tha^{-1}$) juga lebih tinggi berbanding V 36 (3.3t $ha^{-1}$).

Dalam eksperimen kedua, terdapat 3 kombinasi rawatan: kepadatan tanaman, umur penuaian dan varieti dalam susunan plot belah belahan dengan 4 replikasi. Umur penuaian disusun sebagai plot utama, kepadatan tanaman sebagai sub plot dan varieti sebagai sub-sub plot. Kepadatan tanaman yang sesuai untuk MHC 123 dan V 36 bagi makanan ternakan adalah pada 666,700 pokok sehektar. Ini adalah berdasarkan MHC 123 mempunyai kandungan protein kasar dan kandungan ADF yang rendah di kepadatan tanaman 666,700 pokok sehektar.

Kepadatan tanaman 444,400 pokok sehektar adalah kepadatan terbaik untuk pengeluaran serat untuk MHC 123 dan V 36. Ini adalah berdasarkan hasil kajian MHC 123 dan V 36 mempunyai hasil berat kering, hasil serat luar dan hasil serat dalam yang tinggi di kepadatan 444,400 pokok sehektar. Hasil berat kering secara signifikannya lebih tinggi ($p<0.05$) pada kepadatan yang rendah, 444,400 pokok sehektar dengan 12.7 tan sehektar diikuti dengan penurunan hasil berat kering kepada 11.5, 11.2 dan 10.3 tan sehektar masing-masing untuk 500,000, 571,500 dan 666 700 pokok sehektar. MHC 123 mempunyai potensi untuk menggantikan V 36. Kelebihan MHC 123 berbanding V36 meliputi hasil daun, hasil batang, bilangan daun per plot, nisbah daun dan batang, indek keluasan daun (LAI), bilangan hari berbunga dan hasil serat luar yang lebih tinggi. Keputusan kajian menunjukkan umur tuaian dan kepadatan tanaman yang optimum berbeza untuk setiap varieti kenaf.

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## APPROVAL

I certify that a Thesis Examination Committee has met on 23 April 2015 to conduct the final examination of Masnira Mohammad Yusoff on her thesis entitled "Harvest age and Planting Density Effects on yield and Quality of Two Kenaf (*Hibiscus cannabinus* L. ) Varieties For Fibre and Animal Feed" in accordance with the Universities and University College Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U. (A) 106] 15 March 1998. The Committee recommends that the student be awarded the Master of Science.

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## DECLARATION

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# LIST OF ABBREVIATIONS

| | | |
|---|---|---|
| ANOVA | : | Analysis of variance |
| As | : | Arsenic |
| BRIS | : | Beach ridges interspersed with swale |
| Cd | : | Cadmium |
| DAP | : | Day after planting |
| et al | : | and friends |
| Hg | : | Mercury |
| LKTN | : | Lembaga Kenaf dan Tembakau Negara |
| MARDI | : | Malaysian Agricultural Research and Development Institute |
| MPa | : | Mega Pascal |
| NIRS | : | Near infrared reflectance spectrophotometer |
| Pb | : | Lead |
| RCBD | : | Randomized Complete Block Design |
| SAS | : | Statistical Analysis Software |
| St | : | Strontium |
| WAP | : | Week after planting |

# CHAPTER 1

# INTRODUCTION

## 1.1 Background

Plant fibre includes natural fibres obtained from stem, leaves, roots, fruits and seeds of plant (Rao and Rao, 2007). Kenaf fibre from the stem is one of the important fibre in the new decade. Kenaf or its scientific name, *Hibiscus cannabinus* is a tropical plant that is grown around the world as a source of animal feed and fibre. Kenaf is a warm season annual fibre crop and is closely related to cotton and jute. Kenaf is cultivated in many countries in the world like Bangladesh, India, Thailand, Australia, Indonesia, Vietnam, Africa, China, Southeast Europe and Malaysia.

Kenaf was introduced in Malaysia in early 2000 (Mat Daham *et al.*, 2006) mainly for use as forage while currently the crop is studied for other purpose such as biocomposite. In Malaysia, kenaf has become an important industrial crop supplying natural fibre source for the manufacture and building material.

## 1.2 Problem statement

Kenaf has a potential to be commercialized but there are a lot of barrier to achieve it. The limiting factor for commercialization of kenaf in Malaysia is lack of suitable variety to be cultivated under Malaysian condition. So far there was only one variety already introduced by MARDI which is V 36. The existing variety has limitations in yield and newer varieties with higher yield and good quality especially for forage and fibre may boost production. Various varieties of kenaf can be found in several countries like China, India and Bangladesh. They are variable in plant growth rate, photosensitivity to day length, stem and leaf colour, leaf and seed shape and the suitability to the different environment. To produce enough biomass of high quality which can be converted to fibre and animal feed there is need to identify kenaf varieties with potential for high biomass yield and specific quality traits (Agbaje *et al.*, 2008). One of the potential varieties is MHC 123.

MHC 123 exhibits good agronomic characteristics compared to V36. New varieties like MHC 123 have to come with new agronomic practices because different varieties have different life spans. Normally for V36 it takes about 6-8 weeks to harvest for animal feed while for fibre it takes about 4 months. For MHC 123 the time to harvest which gives high dry matter yield with good quality may be different. Other factors such as planting density are also important and a combination of optimal planting density and appropriate harvest time are the key to maximixing kenaf yield and quality. Previous recommendation for cultivation were based solely on using existing farm equipment for kenaf production to minimize start-up cost and the lack of herbicide to control weeds in kenaf planted in narrow row. Practicing various planting densities may be useful in tailoring kenaf fibre production to its desired use. For example, the narrow row spacing in kenaf not only increases the total biomass yield, but also increases the bast fibre percentage of the stalks (Baldwin and Graham, 2006). A better understanding on how the yield component (plant population, plant height, stalk and leaf yield, total biomass) are affected by agronomic practices and other factors needs to be studied especially in Malaysian condition.

The best economically viable management practices for growing kenaf must be developed (Danalatous and Archontoulis, 2010). This is necessary for farmers and industrialist to benefit from the recent innovative use of kenaf as a bio-renewable energy resources.

## 1.3 Aims and research objectives

The aims of the study were to identify the suitable harvesting age and planting density for new kenaf variety for forage and fibre to fit the high kenaf demand. The specific objectives of the experiments were:

1) To determine the optimum harvesting age for forage and fibre production for MHC 123 and V 36.
2) To determine the suitable planting density of MHC 123 and V 36 for animal feed and fibre production.
3) To compare MHC 123 with V 36 in terms of productivity and quality as animal feed and fibre.

# REFERENCES


Abdullah, O., Wong, C. C., Zainal Abidin, H., Abdul Aziz Atta, M., Kassim, B and Ayob, H. (2006). Consolidation of production technologies for commercialization of kenaf cultivation in Malaysia. Proceeding of The Fourth Technical Review Meeting on Research and Development of Kenaf Production for Animal Feed and Fiber, Jan. 24-25. Ed: Mat Daham, M.D., Abdullah, O. and Wong, C.C. MARDI: Kuala Lumpur, 2006.

Acreche, M. M., Gray, L. N., Collavino, N. G. and Mariotti, J. A. (2005). Effect of row spacing and lineal sowing density of kenaf (*Hibiscus cannabinus* L.) yield components in the north-west of Argentina. *Spanish Journal of Agricultural Research* 3 (1): 123-129.

Adamson, W. C., Long, F. L. and Bagby, M. O. (1979). Effect of nitrogen fertilization on yield, composition and quality of kenaf, *Agronomic Journal*. 71: 11-14.

Agbaje, G.O., Saka, J.O., Adegbite. A.A. and Adeyeye, O.O. (2008). Influence of agronomic practices on yield and profitability in Kenaf (*Hibiscus cannabinus* L.) fibre cultivation. *African Journal of Biotechnology* Vol 7 (5): 565-574.

Ahmad Amel, B., Paridah, M. Tahir., Sudin, R., Anwar, U. M. K and Ahmed S. Hussein. (2013). Effect of fibre extraction methods on some properties of kenaf bast fibre. *Industrial crops and products*.117-123.

Akihiro, N., Hisato, K., Yutaka, K. and Yukio, S. (2012). Characterization of kenaf phloem fibers in relation to stem growth. *Industrial crops and products*, 37:547-552.

Alexopolou, E., Christou, M., Mardikis, M, M. and Chatziathanassiou, A. (2000). Growth and yields of kenaf varieties in central Greece. *Industrial crop and product*, 11: 163-172.

Alexopolou, E., Li, Y., Papatheohari, H., Siqi, D. and Scordia, G. T. (2015). How kenaf (*Hibiscus cannabinus L.*) can archive high yields in Europe and China. *Industrial crops and products* 68.131-140.

Alexopolou, E., Papatheohari, Y., Picco, D., Di Virgio, D. and Monti, A. (2013). Crop management. In *Kenaf: a Multi-purpose crop for several industrial applications* ed. Monti, A and Alexopolou, pp. 59-82. New York: Springer.

Aminah, A., Hasim, I., Burahnuddin, M. and Mohd Yusoff, C. E. (2009). *The Effect of Sequential Planting and Planting Date of Kenaf for Fibre Yield on Bris in Telong.* JK Teknikal Tanaman Kenaf MARDI. MARDI: Kuala Lumpur.

Aminah, A., Wong, C. C. and Hasim. I. (2006). Production potential of kenaf for forage and fiber on bris under small holder management systems. In Proceeding of The Fourth Technical Review Meeting on Research and Development of Kenaf Production for Animal Feed and Fiber, Jan. 24-25,

2006. Ed.; Mat Daham, M. D., Abdullah, O. and Wong, C. C. MARDI: Kuala Lumpur, 2006.

Anon, (2014). Lembaga Kenaf dan Tembakau Negara. http:// www.lktn.gov. my/index.php/my/. Accessed on 23 May 2015.

Anut, C., Chakrapong, C., Orawan, C. and Piyaros, K. (2009). Evaluation of yield and nutritive value of kenaf (*Hibiscus cannabinus L.)* at various stage of maturity. *Pakistan Journal of Nutrition 8*(7): 1055-1058.

Asfaliza, R., Wong, C. C. and Muhammad Ghawas, M. (2003). A preliminary study on kenaf (*Hibiscus cannabinus* L.) accessions for fibre and pulp production. *Journal Tropical Agriculture and Food Crop Science.* Kuala Lumpur 31(1): 29-34.

Ashori, A., Harun, J., Raverty, W. D. and Mohd Yusoff, M.N. (2007). Chemical and Morphological Characteristic of Malaysian Cultivated Kenaf (*Hibiscus cannabinus*) Fiber. Polymer-plastic Technology and Engineering. Ed. Taylor and Francis. London. pp 134.

Baldwin, B. S and Graham, J. W. (2006). Population density and row spacing effects on dry matter yield and bark content of kenaf (*Hibiscus cannabinus* L.). *Industrial Crops and products* 23 pp 244-248.

Bhangoo, M. S., Cook, H. S. and Henderson, J. (1986). Effect of planting date, nitrogen levels, row spacing and plant population on kenaf performance in the San Joaquin Valley, California. *Agronomic Journal* pp 78:600-604.

Bitzer, M. J. and Bruening, B. (1997). Effect of varieties and row width on kenaf yields. In Proceeding of Ninth Intstitute Kenaf Association Conference. Scottsdale, March 27-29, pp 67.

Carla, P., Roberto, B. and Parrizia, M. (1994). Yield potential and adaptation of kenaf *(Hibiscus cannabinus). Industrial Crops and Products* 3:11-15.

Charles, L. W. III. (1993). Crude protein and yield component of six kenaf cultivars as affected by crop maturity. *Industrial Crops and Products*. USDA. 27-31.

Charles, L. W., Harban, L., Bhardwaj. and Venito, K. B. (2002). Kenaf production: fiber, feed and seed. In T*rends in new crops and new uses*, ed. Janick, J. and Whipkey. pp 104: ASHS press.

Clark, T. F. and Wolff, I. A. (1969). A search for new fiber crops, XI. Compositional characteristic of Illinois kenaf at several population densities and maturities. TAPPI 52: 2606-2116.

Danalatos, N. G, and Archontoulis, S. V. (2010). Growth and biomass productivity of kenaf (*Hibiscus cannabinus*, L.) under different agricultural inputs and management practices in central Greece. *Industrial Crop and Products* 32: 231-240.

Danalatos, N. G, and Archontoulis, S. V. (2004). *Potential growth and biomass productivity of kenaf (Hibiscus cannabinus L.) under central Greek conditions: 1. the influence of fertilization and irrigation*. Paper presented at second World conferences on biomass for energy, industry and climate protection, Rome Italy. May 2004.

Danilo, S., Giorgio, T. and Salvatore, L. Cosentino. (2013). Crop physiology in relation to agronomic management practices. In *Kenaf: a Multi-purpose crop for several industrial applications* ed. Monti, A and Alexopolou, green energy and technology pp:17-44. Springer.

Defang, L. and Siqi, H. (2013). The breeding of kenaf. In *Kenaf: a Multi-purpose crop for several industrial applications* ed. Monti, A and Alexopolou, green energy and technology.45-58. Springer.

Fageria, N. K., Baligar, V. C. and Clack, R. B. (2006). Physiology of crop production. New York: The Harworth Press, Inc. pp: 345.

Falasca, S. L., Ulberich, A. C. and Pitta Alvarez, S. (2014). Possibilities for growing kenaf *(Hibiscus cannabinus L.*) in Argentina as biomass feedstock under dry subhumid and semiarid climate conditions. *Biomass and Bioenergy* 64, 70-80.

Higgins, J. J and White, G. A. (1970). Effect s of plant population and harvest date on stem yield and growth components of kenaf in maryland. *Agronomic Journal* 62:667-668.

H'ng, N. G., Khor, B.N., Tadashi, N., Aini, A.S.N. and Paridah, M. T. (2009). Anatomical structures and fiber morphology of new kenaf varieties. *Asian Journal Science Resources,* 2(3):161-166.

James, L. Gurram. L., Subbarao. D., Stokke, D., Heath, H. G. and Muthukumarappan, K. (2004). Mechanical properties of biorenewable fiber/plastic composites. *Journal of Applied Polymer Science* Vol 93, Issue 5 pp 2484-2493.

John, S., Nilmina, P. J., Dissanayake, Amandeep S. V. and Wayne, H. (2010). Part 1. Fibre as reinforcements, a review of bast fibre and their composites. Elsevier ltd. pp.1335.

Kirby, R. H. (1965). *Mallow family (Malvacea*). In vegetable fibre, botany, cultivation and utilization. Leonard Hill books, London, Interscience Publisher Inc, New York pp 213.

Kipriotis, E., Heping, X., Vafeiadakis, T., Kiprioti, M. and Alexopolou, E. (2015). Ramie and kenaf as feed crops. *Industrial crops and product* 68 ; 126-130.

Liang, J. B and Chantiratikul, A. (2004). Effects of replacing alfalfa hay and/or soybean meal with kenaf in diets of lactating cows. In Proceeding *of the Third* Technical Review Meeting on Research and Development of Kenaf Production for Animal Feed and Fibre, May. 25-26. Ed.; Mat Daham, M.D., Abdullah, O. and Wong, C.C. MARDI: Kuala Lumpur, 2004.

Liang, J. B., Paengkoum, P and Chantiratikul, A. (2003). Potential of kenaf as protein forage for ruminant livestock. In Proceeding of the Second Technical Review Meeting on Research and Development of Kenaf Jan 7-8, 2003. Ed.; Mat Daham, M.D. and Wong, C.C. MARDI. Kuala Lumpur.

Liu, L J., Chen H. Q., Dai X. B., Wang, H. and Peng, D. X. (2012). Effect of planting density and fertilizer application on fiber yield of ramie (*Boehmeria nivea*). *Journal of Integrative Agriculture.* 11(7): 1199-1206.

Maiti, R. K and Dasgupta, A. (1972). Comparative microscopy of ten varieties of mesta (kenaf) in relation to yield and quality. *Textile Resources Journal.* 42: 648-649.

Mambelli, S and Grandi, S. (1995). Yield and quality of kenaf (*Hibiscus cannabinus* L.) stem as affected by harvest date and irrigation. *Industrial Crops and Product* 4:97-104.

Md. Majibur, R. K., Ying, C., Tamara, B., Claude, L., Hubert, l., Qingjin, P. and Wen, Z. (2011). Fineness and tensile properties of Hemp (*Cannabis sativa* L.) fibres. *Biosystem Engineering* 108, 9-17.

Martini, M. Y. (2012). *Physiological and Environmental Constraint to Winter Forage Crops Production*. PhD thesis, Lincoln University New Zealand.

Masnira, M. Y. (2011). Pengeluaran biji benih kenaf. *Buletin Teknologi Tanaman* bil 8 pp: 39-46. MARDI, Kuala Lumpur.

Mat Daham, M. D. (2010). *Slaid presentation.* MARDI report. Serdang.

Mat Daham, M. D. (2005). Kenaf tanaman berpotensi tinggi. *Agromedia* ISSN: 1511-094X bil 18. Pp: 4-13. MARDI, Kuala Lumpur.

Mat Daham, M. D. and Masnira, M. Y. (2009). Kenaf tanaman alaf baru. *Agromedia* ISSN: 1511-094X bil 30 3/2009 pp: 34-37. MARDI, Kuala Lumpur.

Mat Daham, M.D., Wong, C.C., Mohd Najib, M.A. and Abdullah, O. (2006). *Manual Teknologi Pengeluaran Kenaf Di Malaysia Edisi Kedua,* MARDI. Serdang 45 pp.

Mohd Edeerozi, A. M., Hazizan, M. A., Azhar, A. B. and Zainal Ariffin, M. I. (2006). Chemical modification of kenaf fibres. Pulau Pinang. *Material letters* pp 61.

Mohd Najib, M. A., Md Akhir, H. and Wan Zahari, M. (2004). Current status of kenaf (Hibiscus *cannabinus L)* production for animal feed and fibre. In Proceeding of the Third Technical Review Meeting on Research and Development of Kenaf Production for Animal Feed and Fibre, May. 25-26. Ed.; Mat Daham, M.D., Abdullah, O. and Wong, C.C. MARDI: Kuala Lumpur, 2004.

Muchow, R. C. (1979). Effect of plant population and season on kenaf (*Hibiscus cannabinus* L.) Grown under irrigation in tropical Australia, influence on the component of yield. *Field Crops Resources* 3: 27-32.

Nik Ablah, N. M, (2012). Kenaf KB 6. *Monitoring and Evaluation Rice and Industrial Crop Research centre.* MARDI Serdang.

Nik Ablah, N. M, (2009). *Nutrient Requirement for Growth and Development of Kenaf Biomass Production.* Technical Kenaf Working Group MARDI: Kuala Lumpur.

Nor Aini A. S., Mohd Basri, H., Hazandy, A. H., Ghizan, S. and Mohd Fadzhel, M. N. (2009). Growth and phenology of kenaf (Hibiscus cannabinus L.) varieties. *Pertanika J. Trop. Agric*. Sci. 32(1): 29-33. University Putra Malaysia Press.

Noor Syahira, N. (2011). *Continuous evaluation and selection of F4 progenies from China with check varieties MHC 36 and MHC 133*. Technical Kenaf Working Group MARDI: Kuala Lumpur.

Noor Syahira, N. (2010). *Kenaf MHC 123.* Technical Kenaf Working Group MARDI: Kuala Lumpur.

Norlin, N., Hazizan, M. A., Mohd Ishal, Z. A. and Abu Bakar, A. (2011). Behaviour of kenaf fibres after immersion in several water conditions. *BioResources* 6(2). 950-960.

Omar, F., Andrzej, K., Bledzki, H. P. F. and Mohini, S. (2012). Biocomposites reinforced with natural fibres: 2000-2010. *Progress in Polymer Sciences* 37:1552-1596.

Patane, C. and Cosentino, S. L. (2013). Yield, water use and radiation use efficiencies of kenaf (*Hibiscus cannabinus*. L) Under reduced water and nitrogen soil availability in a semi-arid Mediteranian area. *European Journal of Agronomy* 46: 53-62.

Patane, C. and Sortino, C. (2010). Seed yield in kenaf (*Hibiscus cannabinus* L.) as affected by sowing time in South Italy. *Industrial Crops and product.* 32:381-388.

Pearson, D. (1976). Chemical analysis of foods. 7th Ed London Churchill Livingstone. 7-11.

Petrini, C., Bazzoci, R, and Montali, P. (1994). Yield potential and adaptation of kenaf (*Hibiscus cannabinus*. L) In north –central Italy. *Industrial Crops and products*, 3: 11-15.

Phillips, W. A., Reuter, R. R., Brown, M. A., Fitch, J. Q., Rao, S. R. and Mayeux, H. (2002). Growth and performance of lamb fed a finishing diet containing either Alfalfa or Kenaf as the roughage source. *Small Ruminant Research* 46: 75-79.

Rao, M. M. and Rao, M. (2007). Extraction and tensile properties of natural fibers: Vakka, Date and Bamboo. *Composite structures* 77: 288-295.

Robynn, A., Larry, C., Burton L. J., Yun, J. and Marisol, T. B. (2013). Sorghum and kenaf biomass yield and quality response to nitrogen fertilization in the Northern Great Plains of USA. *Industrial crops and Product*. 50:159-163.

Roger, M. R. and James, S. H. (1999). Changes in kenaf properties and chemistry as a function of growing time. In *Kenaf Properties, Processing and product*, ed. Roger, M.R, and James, S.H, pp 33-41. Mississipsi State University.

Roslan, I., Shamshuddin, J., Fauziah, C. I. and Anuar, A. R. (2011). Fertility and suitability of the spondosol formed on sandy beach ridges interspersed in the Kelantan, Terengganu plains of Malaysia for kenaf production. *Malaysian Journal of Soil Sciences* vol. 15:1-24.

Salih, F. A. (1983). Effect of variety, sowing date and nitrogen levels on kenaf yields and its components in the Kenana area of the Sudan. *Journal Agronomy Crop Science* 152: 48-55.

Sarma, T. C., Ali, F., Boldloi, D. N., Chalika, B. P and Baruah, J. N. (1996). Studies on biomass production of kenaf. (*Hibiscus cannabinus* L.). In proceeding of symposoium on plantation opportunies in India plantation crops; opportunities and constraints, vol. 1. Oxford and IBH Publishing Co. New Dehli pp: 143-151.

Sellers, T. Jr., Reichert, N. A., Eugene, P. C., Marty, J. F. and Karen, W. (1999). In *Kenaf properties: Processing and Products*. Ed. Roger, M.R, and James, S.H Mississippi State University.

Van Soest, P. J. (1967). Development of a comprehensive system of feed analyses and its application to forages. *Journal of Animal Science*. 26:119-128.

Wan Zahari, M., Mohd Najib, M. A, and Mohd Shukri, H. I. (2004). Processing of kenaf as a protein feed for beef cattle and the use in other livestock. In proceeding of the Third Technical Review Meeting on Research and Development of Kenaf Production for Animal Feed and Fiber, May 25-26 2004. Ed.; Mat Daham, M.D., Abdullah, O. and Wong, C.C. MARDI: Kuala Lumpur.

Wan Zahari, M., Sato, J., Furuichi, S., Azizan, A. R. and Mohd Yunus, I. (2003). Commercial processing of oil palm fronds feed in Malaysia. In Proceeding of the 8$^{th}$ FAO Regional Working Group Workshop on Grazing and Feed Resources for South East Asia. September 22-28. Kuala Lumpur.

White, G. A., Cummins, D. G., Whitely, E. L., Fike, W. T., Greig, J. K., Martin, J. A., Killinger, G. B., Higgins, J. J, and Clark, T. F. (1970). Cultural and Harvesting Methods for Kenaf. USDA Production Research Report. Washington, DC.

Wilson, F. D and Joyner, J. F. (1969). Effects of age, plant spacing and other variables on growth, yield and fiber quality of kenaf (*Hibiscus cannabinus* L). USDA Technical Bulletin. U.S Government Printing Office, Washington, DC.

Wong, C. C., Asfaliza. R. and Khairudin. G. (2003). Assessment of forage and fibre productivity of selected kenaf accessions/cultivars in Malaysia-phase 2. In Proceeding of the Second Technical Review Meeting on Research and Development of Kenaf Jan 7-8, 2003. Ed: Mat Daham, M. D. and Wong, C. C. MARDI. Kuala Lumpur.

Wong, C. C., Mat Daham, M. D. and Abdullah, O. (2008). Effects of defoliation (cutting) on forage yield and quality of selected kenaf accessions. J*ournal Tropical Agriculture and Food Crop Science,* 36 (1): 21-28.

Zhou, C., Ohtani, Y., Sameshina, K. and Zhen, M. (1998). Selection of plant population of kenaf (*Hibiscus cannabinus* L.) as a papermaking raw material on arid hillside land in China. *Journal Wood Sci*ence 44: 296-302.